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A RE-EVALUATION OF W. H. WRIGHT'S PLATES OF THE 1924 AND 1926 OPPOSITION OF MARS

by

R. A. Wells

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A RE-EVALUATION OF W. H. WRIGHT'S PLATES OF THE 1924 AND 1926 OPPOSITION OF MARS

Introduction

During the forty years since the announcement by W. H. Wright (1) that Mars photographed on infrared plates has a smaller diameter than when photographed on ultraviolet plates considerable disagreement has arisen among observers as to the magnitude of the difference. For example Trumpler (2), Ross (3), Slipher (4), and Marz (5) all confirm the effect with values ranging from 2 to 7 percent difference in the red and violet diameters, whereas Dollfus (6) has recently found no difference whatsoever. The purpose of the present author's program was to re-examine the original plates of the 1924 opposition from which Wright made the discovery mentioned above. In addition a large number of plates from his 1926 series was analyzed, since he apparently did not have the time to continue the measurements with the detail in which he considered his data from 1924 (7, 8).

The plates were analyzed by a Gaertner micrometer measuring engine and the newly installed Lick Observatory Gaertner microphotometer. With respect to the latter the author felt a comparison of the measuring techniques of extended objects both by micrometer and microphotometer warranted close attention. Using the microphotometer to obtain the brightness profile of the planet a more accurate determination of the diameter might be achievable, independent of the more subjective eye-setting of a fine hairline micrometer wire on the planet's limb.

I. Experimental Techniques - plates, micrometer, microphotometer

In this program a total of 84 plates was measured on the micrometer. This number includes 36 from 1924 and 48 from 1926. In each year half of the total plates were the original negatives and half were positive glass copies. In 1924 only 18 plates were measured by the microphotometer and only 12 in 1926.

The plates from 1924 were obtained primarily at λ 7600 and λ 4400 A. Those exposed in 1926 were in six colors. The filters Wright employed had maximum transmissions at $\lambda\lambda$ 7600, 6500, 5700, 5300, 4400, 3700 A. There is no available information on whether Wright reduced this series of photographs, therefore the author selected 48 plates from this series for measurement.

The problem of chief concern with the photographic plates is scattering of light in the emulsion. From the nature of the emulsion it is to be expected that light incident from a disk-shaped object will be scattered around the edges of the produced image. A semi-quantitative analysis of scattering in Wright's plates was attempted by observing diameter changes with varying exposure times. This discussion appears in Section II.

The same techniques used by Wright were employed by the author in setting the micrometer hairline on the limbs. For red images (λ 7600A) the hairline was set as far off the limb as conscience would allow to compensate for limb darkening (9). For the violet images (λ 4400A) the hairline was set on a region of average gain density between the higher density of the planet proper and the lower density of the background, i.e. the hairline was in general set in on the limb for violet images. Wright stated that his technique would compensate for any gross differences ascribed to plate effects, limb darkening in the red, and limb brightening in the violet (9).

Three settings were made on each limb of the image, the plate was reversed and the same measurements made again. This method was to eliminate backlash effects of the screw by making measurements only in the same direction.

Only the apparent equator was measured and was determined by placing the image in the viewer of the micrometer until equal quadrants were obtained with respect to the cross-hairs. To make certain that the apparent equator was at all times parallel to the line joining the two points defining the measured diameter the plate was initially set by the polar axis of the measuring engine according to the ephemeris position angle of Mars for the time and date of exposure.

In reading through the literature on measurements of extended sources, particularly that of the diameter of Mars, the author has found that the measuring techniques have been much too subjective when, as in the case of Mars, small differences in size are to be detected. Wright himself said:

> "In view of the care taken to measure only fully exposed photographs in this color (λ 7600A), and to set the measuring wire as far out as conscience would permit, I am reluctant to admit the likelihood of a negative systematic error of that size." (9)

The desire for greater accuracy prompted the author to attempt measurements by microphotometer. The following technique was employed in securing the data and final reductions.

Each of the plates was positioned on the carriage of the instrument with the aid of a ruled protractor according to the ephemeris position angle of Mars at that date. The disk was scanned in an equatorial direction with a slit length slightly shorter than the diameter of the image. The slit size was 1000μ x 10μ. A slit of this length was used so that background noise from the plate's granularity would be cut to a minimum.

The apparent diameter was defined as the distance between the intersection of the slope with the background scan, figure 1. Using a slit length equivalent to the diameter of the image does not produce a contour which is the true brightness profile at the planet's limb, obtained with a small square slit. This definition gives the point at which the planet ends and the plate background begins. The distance from limb to limb could then be measured by an engraved rule. Knowing the scanning rate of the instrument and the rate of line feed for the tracing paper, this distance could be expressed in millimeters and the remaining reduction would be the same as for the micrometer data.

The IBM 7090 computer was utilized to reduce all data. This step was felt necessary because the large volume of numbers could then be handled speedily and accurately.

The program for the computer was divided into three basic parts. The first derived the actual size of each image as it appeared on the plate; the second computed a plate scale factor and introduced the distance to Mars for the given date into the computer's memory; and the third utilized the results of steps one and two in making the actual conversion to seconds of arc reduced to one astronomical unit.

II. Correction Factors

Positive plates were included in the survey since a small error is to be expected by encroaching on the planet's limb with a micrometer hairline. Hence, by averaging the measurements from a negative and positive image, the error introduced by encroachment should be nullified.

To guard against further effects from improper exposure times of the positive contact copies, a photographer's battery-operated intensitometer related the background plate density of the negatives to correct exposure times which would produce the same relative densities on the positive copies. This method was effected by first securing one negative as a standard and making several test copies at random exposures. The copy which had the same background density as the negative would then have the standard exposure time from which all others would be scaled with respect to varying background densities of the negatives.

At best it is very difficult to obtain a quantitative understanding of the interactions of light in the emulsions. The plates Wright used were made by the late Dr. Mees at Eastman Kodak Laboratory and no records were kept containing information concerning their properties.

Fortunately Wright made as many as a dozen different exposures of Mars on each plate. A look at the diameter variation with exposure time should provide some information.

In 1926 standard intensity spots are impressed on the plates. In this case a diameter variation with intensity should give information on the inherent scattering properties of the emulsion.

Figure 2 shows a linear increase in the planet's diameter with exposure time for the infrared images by micrometer. Figure 3 is the same curve obtained by microphotometer but it has a steeper drop-off at the beginning than is apparent in figure 2. Figures 4 and 5 are the same type of curves for the violet images. If the initial parts of these curves are neglected since there seems to be more of an error in the observation at those points, the graphs in figures 4 and 5 would be identical*.

Figure 6 shows the inherent scattering properties of the emulsion. The curved section has a maximum slope of 0.30 mm/unit intensity. The curves of the planet at λ 7600A have a slope of 0.15 and the curves at λ 4400A have a slope of 0.25. Since the brightness profile at the limbs of the planet is not a step function and the wavelength dependence of scattering in the emulsion cannot be accurately determined these graphs serve no useful purpose other than indicating that scattering is present. In addition it is difficult to determine how grossly scattering affects the difference in the diameter at the two wavelengths.

Considering the difficulty in obtaining scattering information from Wright's plates the diameter difference between 7600A and 4400A is probably masked to some extent by scattering in the emulsion; and therefore it is still uncertain if Wright's phenomenon is a real effect.

Because of the differences in exposure times, variations in transparency of the air and in the sensitivity of the plates, the images of Mars are not all of the same intensity, and it must be expected that the results of the individual diameter measures depend somewhat on this factor (2). Trumpler investigated these relations, developing a correction formula for diameter variation with intensity. But since he found that a threefold

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*The points of observation at one second exposure time contain a large probable error because the images at this exposure are extremely faint and difficult to measure.

overexposure of the planetary images produced only an error of about 0.06" in the diameter measures, the factor was neglected in his reductions (2).

This author's analysis of Wright's plates stands in direct contradiction to Trumpler's work as in evident from figures 2, 3, 4, 5. It has been definitely shown that the diameter of Mars does increase with exposure time and intensity. Figure 6 proves that scattering in the emulsion takes place although the extent of scattering is unknown and a means of correcting for it is difficult to develop.

Since exposure times and intensity play such an important role, plates of the same exposure times and same order of uniformity were measured as a means of minimizing these emulsion effects. The measuring technique described before was used because several observers argue that Wright's phenomenon is due entirely to limb darkening in the infrared which will always tend to make the measured diameter too small. Barabascheff and Timoshenko pointed out that the extreme edge of the planet may not be recorded in red light, where as in the blue image the edge is in some cases brighter than in the middle (13). W. W. Scharonow (14) also favored this explanation. The data presented later, however, may still be criticized on the basis of intensity variation and scattering in the emulsion.

For the phase correction the following derivation according to R. J. Trumpler was used (2). Assuming Mars to be a circular planetary disk, the limbs will be circular while the terminator at any phase angle will be elliptical. The two points T and T' where the micrometer wire is tangent to the illuminated disk do not lie on the same diameter.

From figure 7, x represents the phase correction to be calculated.

It can be expressed as a function of ϕ (greatest defect of illumination; see diagram) and α (angle between micrometer wires and cusp diameter). Letting the radius of the planet by unity and OT' = r, from triange OT'A we have

$$(1)\quad x = 1 - r\cos(\gamma - \alpha)$$

$$= 1 - r\cos\gamma\ \cos\alpha - r\sin\gamma\ \sin\alpha;$$

from triangles ODT' and ODB:

$$(2)\quad r\cos\gamma = (1 - \phi)\cos\beta$$

$$r\sin\gamma = \sin\beta$$

and from triangles CBD and CT'D:

$$(3)\quad (1 - \phi)\tan\beta = \tan\alpha .$$

Using (2) to eliminate r and γ from (1) and simplifying we have

$$x = 1 - (1 - \phi)\cos\beta\ \cos\alpha - \sin\beta\ \sin\alpha$$

and eliminating β by (3) and developing in powers of ϕ, we have finally:

$$x = \phi\cos^2\alpha - \frac{\phi^2}{8}\sin^2 2\alpha - \frac{\phi^3}{8}\sin^2 2\alpha\cos^2\alpha \ldots\ldots$$

From the American Ephemeris and Nautical Almanac

$$\phi = 2(1 - k)$$

where k is the ratio of the illuminated portion of the disk to the entire disk.

For the polar diameter $\alpha = P - Q$

For the equatorial diameter $\alpha = 90^\circ + P - Q$

where P is the position angle of the axis of rotation measured eastward from the north point of the disk, and Q is the position angle of the radius of the disk which passes through the point of greatest defect of illumination (i.e. of the radius perpendicular to the line joining the cusps) measured eastward from the north point of the disk.

Since all measurements were made in an equatorial direction, the appropriate parameters for determining the phase in this direction were used. The correction formula is applied to the diameter of the planet in the following manner. Letting the diameter of Mars be unity as in Figure 8, and the amount of correction be denoted by x, we have

$$D_{Obs} = (1 - x)\ D_{True}$$

or simply

$$D_{True} = \frac{D_{Obs}}{1 - x} .$$

The second correction which accounted for the time rate of change of distance from Earth to Mars was applied to each image. The images with exposure times within at least one-half hour of each other were given the same correction. In actuality, the orbital motion of Mars produces a change in approximately the last two digits of the six-digit number expressing the distance. However, this change is insignificant compared with the accuracy in measuring the images. For times greater than thirty minutes, and especially times approaching one hour, the change becomes more significant.

To obtain the plate scale in sec of arc/mm produced by the optical system used in conjunction with the Lick Crossley reflector Wright secured several plates of the double stars θ Serpentis and 61 Cygni.

For 1924 ten images from eight plates were measured for scale. Six of these images were at λ 4400A and four were at λ 7600A. The images on all plates were rather poor in quality and Wright's observing notes pointed out the fact that guiding the telescope was, at most, erratic for these plates. In all cases, the images appeared as double galaxies rather than double stars. To help minimize setting problems, the hairline was positioned at the central density region of each star. For the 1926 observations in six colors ($\lambda\lambda$ 7600, 6500, 5700, 5300, 4400, 3700A) four plates of the same double stars were obtained -- two at λ 7600A and two at λ 4400A -- for the scale factor.

Wright was concerned about correcting for a possible difference in scales at the two different wavelengths ($\lambda\lambda$ 7600A and 4400A) employed in 1924 due to chromatic aberration. Reducing his measurements he found a 1.7 percent difference in red over violet (7). The author examined the scale plates and found a 0.7 percent difference in violet over red wavelengths. These differences were neglected by Wright and this author in the final reductions.

III. Results and Discussion of Data

Table I contains the 1924 values of the present series of reduction for the red images and Table II the same for the violet images. Table III contains the six-color values for 1926.

Wright found the diameter of Mars to be 8.86" in the red and 9.13" in the violet. These values amount to a difference of 0.27" or ca 3 percent. These results are, however, somewhat too small for the red images as was shown by F. E. Ross in 1926 (3). Ross conducted laboratory experiments on the same type of emulsions used by Wright in 1924. His results showed a small effect on kryptocyanin plates (λ 7600A) which gave images 0.30 mm smaller than any other plate tested at this sensitivity. Thus he states:

> "...there remains...a constant edge effect amounting to 0.15 mm for each edge (of the planet), applicable to the infrared plates (7600A) independent of the size of the image. If this were applied to the measures of Wright it would reduce the effect he found from 3 to 2 percent..." (3)

Using Ross' correction factor, this author still found a 3 percent effect with values of 9.25" in the red and 9.53" in the violet giving a difference of 0.28". One should keep in mind that the value 0.28" contains Ross' empirical correction whereas Wright's value 0.27" does not.

Not much information is obtained from the new micrometer reductions for 1924, except that a difference in diameters exists on the order of 3 percent, even after applying Ross' correction for the infrared images.

There is yet the question as to how accurate these new values are. The subjectivity in using the eye to set a hairline on the limb of a small image has already been mentioned. More interesting, however, is a comparison of the values in the two years of observation. The infrared diameter is exactly the same while the value at λ 4400A in 1926 compared to the value in 1924 at the same wavelength is significantly larger. It was assumed that the intermediate wavelengths in 1926 would disagree with corresponding values in 1924 had they been recorded. By generalizing this fact to any year of observation, which is a valid argument since other observers (e. g. Dollfus gives 9.44" at 4700A) in the past 40 years have obtained varied results, it is quite likely that we have an indication of layers in the Martian atmosphere which are highly variable in extent, and which are either particles acting as scattering centers or gaseous constituents acting as absorbers. Both of these conditions indicate a variable albedo for the atmosphere.

Fessenkoff (10) calculated brightness profiles for Mars and has shown that the theoretical broadening of the Martian disk by an isotropic, single-scattering homogeneous atmosphere can amount to no more than about 1 percent. Even if such simplifying assumptions about the atmosphere were not made, the difference would not be large enough to falsify grossly this conclusion (11). Recently Spinrad, Kaplan, and Münch (12) derived a surface pressure on the order of 15-25 millibars. This reduction by a factor of 4 from the previously accepted value for the pressure will increase Fessenkoff's results only slightly.

In addition, Dollfus had obtained brightness profiles of Mars for his diameter determination (6). All of his contours for various pressures and brightness show broadening amounting to no more than 0.5 percent. Moreover, at the altitudes determined by the difference in the red and violet diameters (100 - 200 km) one would suspect that the atmosphere is much too tenuous to scatter light efficiently enough to produce the observed effects.

If one assumes a dust layer of some type of particles in the atmosphere then the observations can be accounted for reasonably. A dust layer hypothesis is rather difficult to explain for there must be some means provided to get the particles up to such extreme altitudes. A pressure of 15 - 25 millibars at the surface gives a density which would probably be much too low to provide this means for throwing heavy dust particles up to the observed altitudes though this is purely speculative. A layer of a condensate such as CO_2 or H_2O would probably fit into the suggested models more easily, though a meteoritic influx of particles could account for the layer.

Tables IV and V contain the microphotometer reduction for 1924 and 1926 respectively. These data are widely different compared to that obtained from the micrometer at the same wavelengths. The explanation for these large differences is that the microphotometer picked up faint extensions of the atmosphere which the eye could not distinguish from the plate background in the case of the ultraviolet plates. The tracings of the planet showed that limb darkening is most pronounced on the infrared plates; hence the microphotometer in this case is probably picking up part of the surface as well as the atmosphere which the eye cannot see. Scattering in the emulsion must be involved but it is difficult to obtain any quantitative estimates as to how much it affects the images. This fact has already been discussed in some detail.

From this work the diameter of the surface as Mars is 6, 682 km. For a comparison the best values known to date are given as 6, 700 km (15), 6, 770 km (11), 6, 790 km (9), 6, 800 km (11), 6, 652 km (2).

IV. Recommendations

This investigation has pointed out in some detail the problems arising in the photographic determination of planetary diameters. These problems can be divided into two classes: Those associated with the optical system and tracking and those concerning the photographic plates.

Since Mars is very infrequently at a favorable opposition, a long focal-length telescope is highly desirable to produce large images of the planet. It is hardly necessary to point out the need for a highly accurate tracking system. In obtaining such photographs of Mars reflectors of long focal lengths such as the 120 inch or 200 inch at Coude focus would be very valuable. Camera optics must be carefully selected, however, to minimize aberrations, and to avoid introducing lens effects which the reflector originally eliminated.

Seeing conditions have a marked influence on the quality of the image at the focus of the telescope. The wavelength dependence of seeing is virtually unknown and until a quantitative understanding of this dependence is obtained the exact nature of the telescope image of a planet will remain in doubt, at least from ground-based observations.

The photographic emulsion introduces the more complex problems. Granularity, edge effects, turbidity, and other common plate characteristics should be thoroughly understood. Light scattering in the emulsion around circular objects or the so-called point-spread functions must be known since the greatest amount of subjectivity enters at this point. The effects of scattering can be minimized to an extent by obtaining as large an image as possible -- hence the need for long focal-length telescopes.

Complete knowledge of the photographic emulsion cannot be over-emphasized. Otherwise photographic plates should be avoided completely, and observations ought to be carried out electronically at the telescope.

Wavelength ranges shorter than 7600A, provided all plate characteristics are accounted for, will provide information as to the structure and extent of the atmosphere. Particularly desirable, however, would be photographs obtained between 7600A and 1 micron. Infrared images are assumed to show the true surface diameter, but 7600A is generally the spectral region concerned and any variability of the diameter out to 1 micron has not been established if any exists.

Methods of measuring the plates should be improved. Visual measurements should be avoided, or at least correlated to brightness profiles of the diameter in a manner similar to Dollfus' visual work (6). Dollfus considered his visual measurements to coincide with limb points about midway on slopes of brightness profile tracings and he developed a correction factor to account for the effect of atmospheric broadening as mentioned in an earlier part of this paper.

Until such objective analyses of Mars are carried out, the diameter and structure of the atmosphere will remain open to criticisms.

ACKNOWLEDGEMENTS

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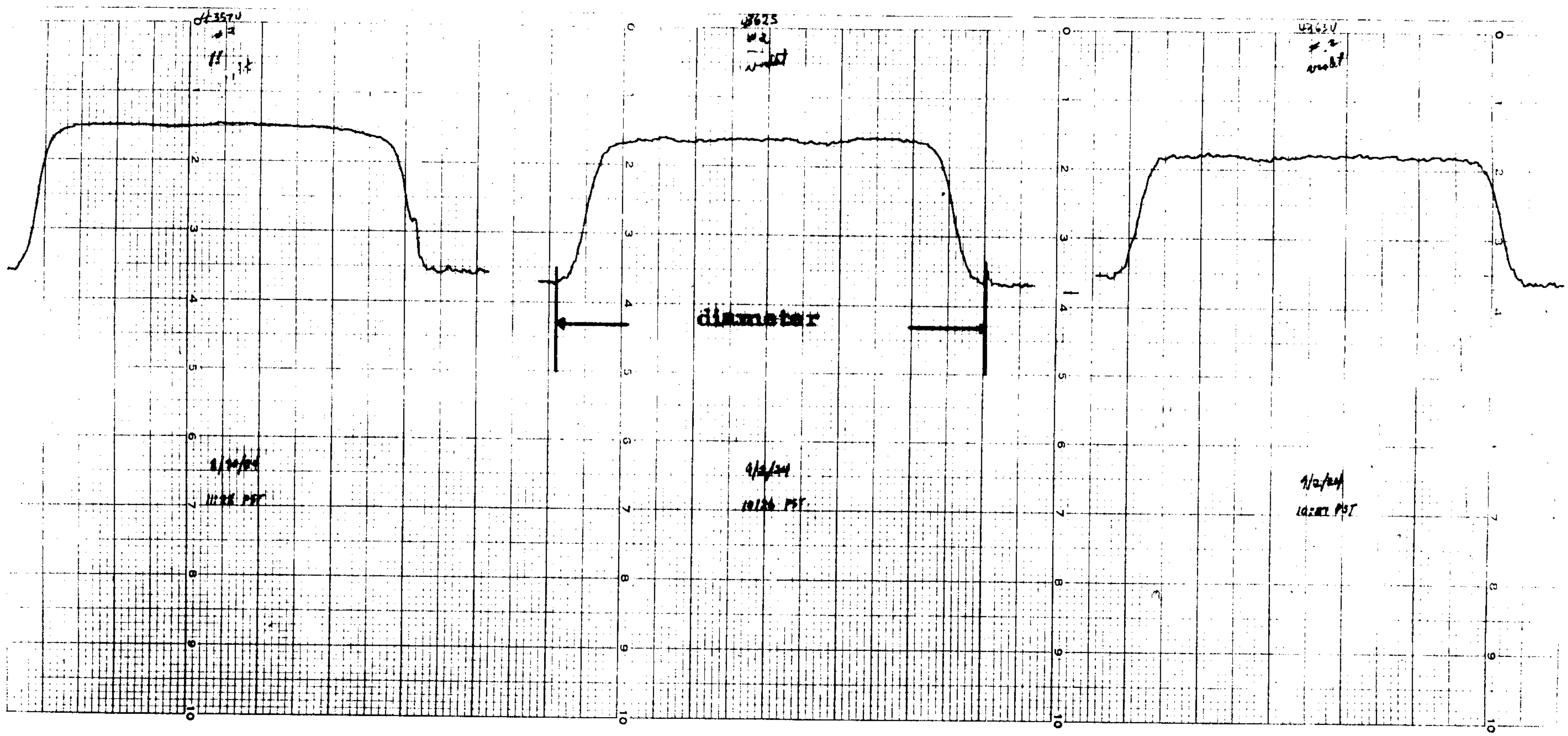


FIGURE 1

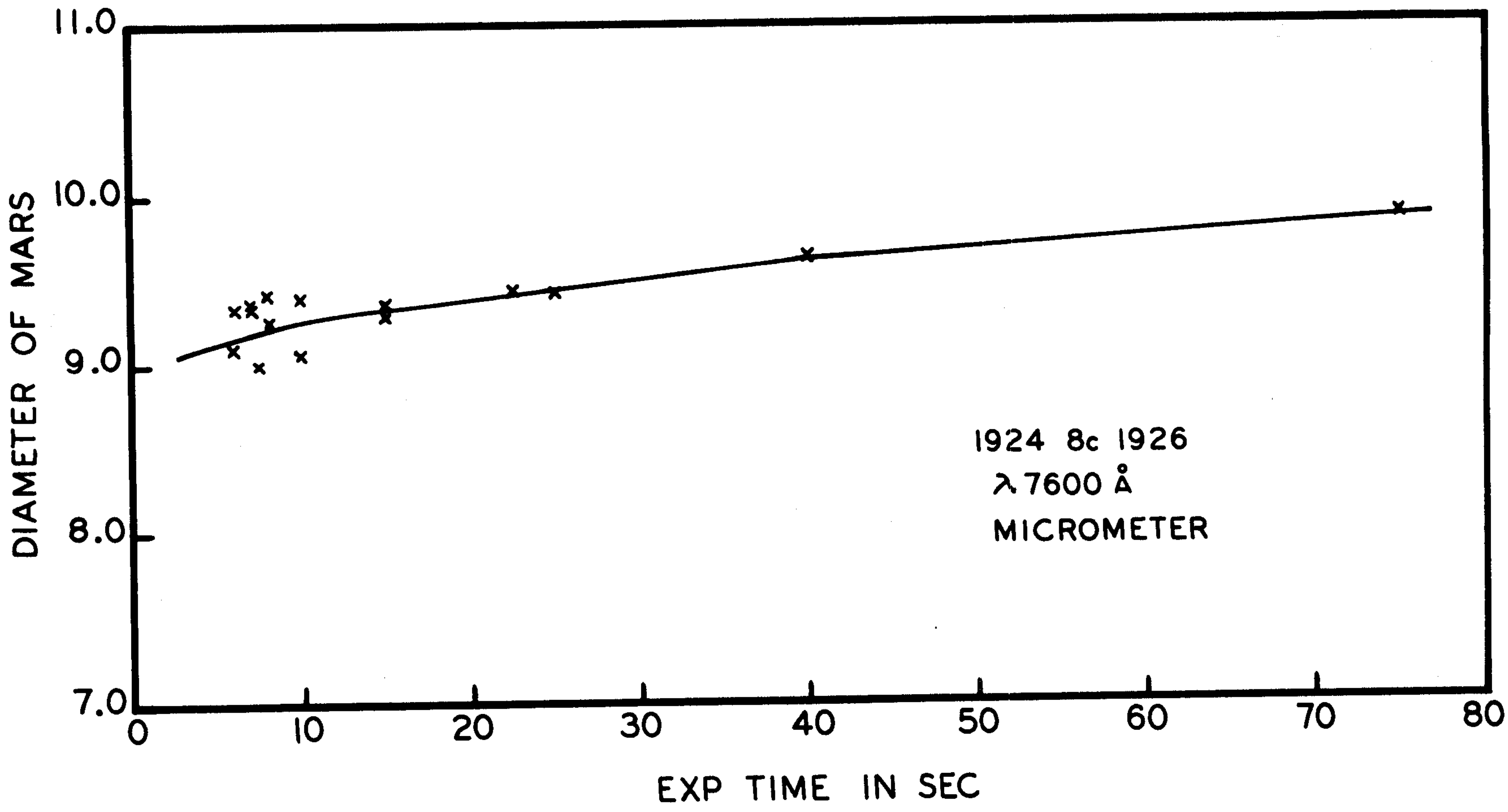

11.0
10.0
9.0
8.0
7.0
DIAMETER OF MARS
1924 8c 1926
λ 7600 Å
MICROMETER
0
10
20
30
40
50
60
70
80
EXP TIME IN SEC

FIGURE 2

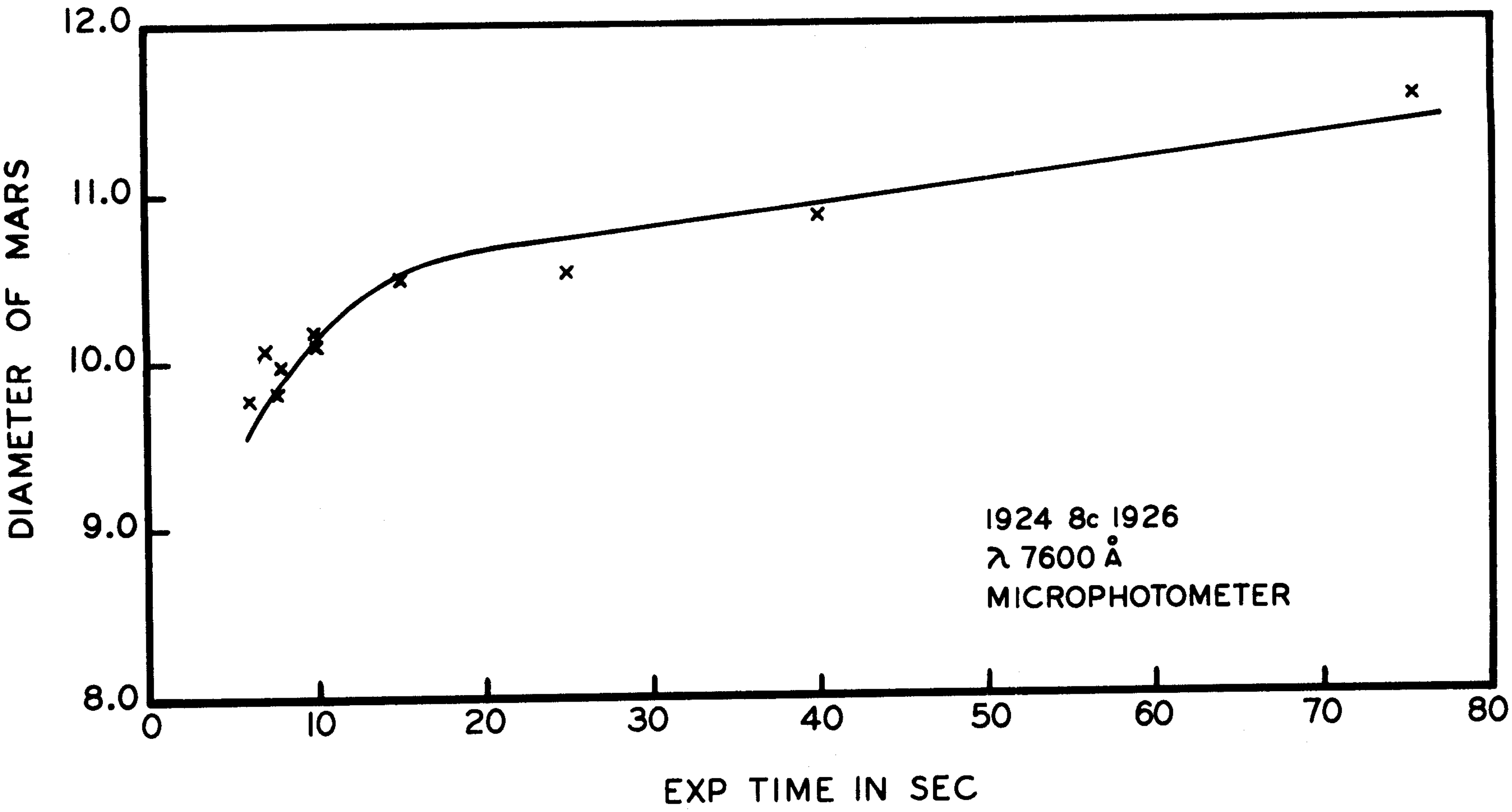
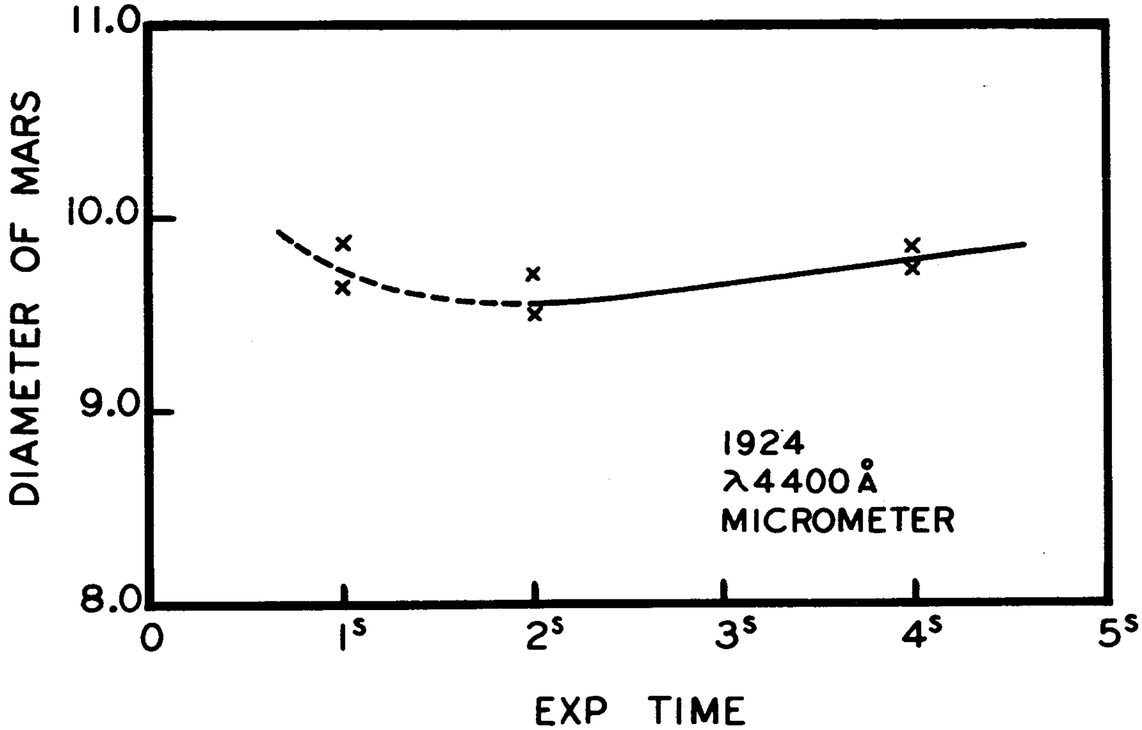
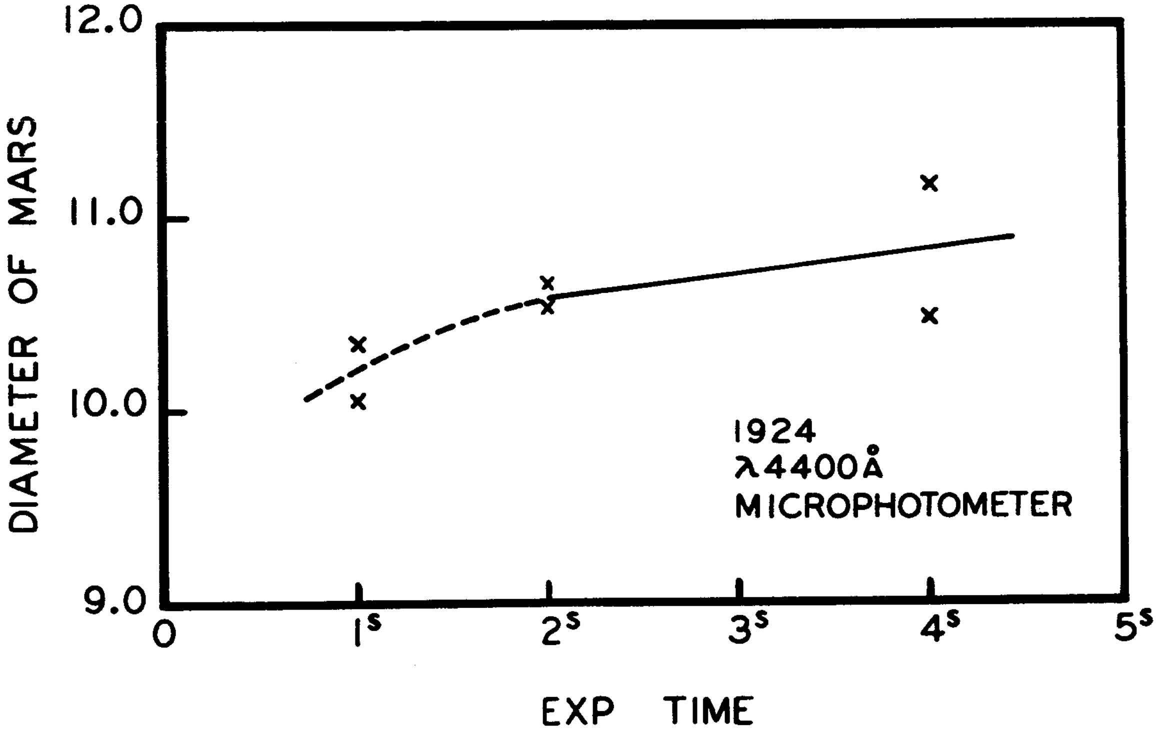

12.0
11.0
10.0
9.0
8.0
DIAMETER OF MARS
0
10
20
30
40
50
60
70
80
EXP TIME IN SEC
1924 8c 1926
λ 7600 Å
MICROPHOTOMETER

FIGURE 3



11.0
10.0
9.0
8.0
DIAMETER OF MARS
1924
λ4400 Å
MICROMETER
0
1s
2s
3s
4s
5s
EXP TIME

FIGURE 4



12.0
11.0
10.0
9.0
DIAMETER OF MARS
1924
λ4400Å
MICROPHOTOMETER
0
1s
2s
3s
4s
5s
EXP TIME

FIGURE 5

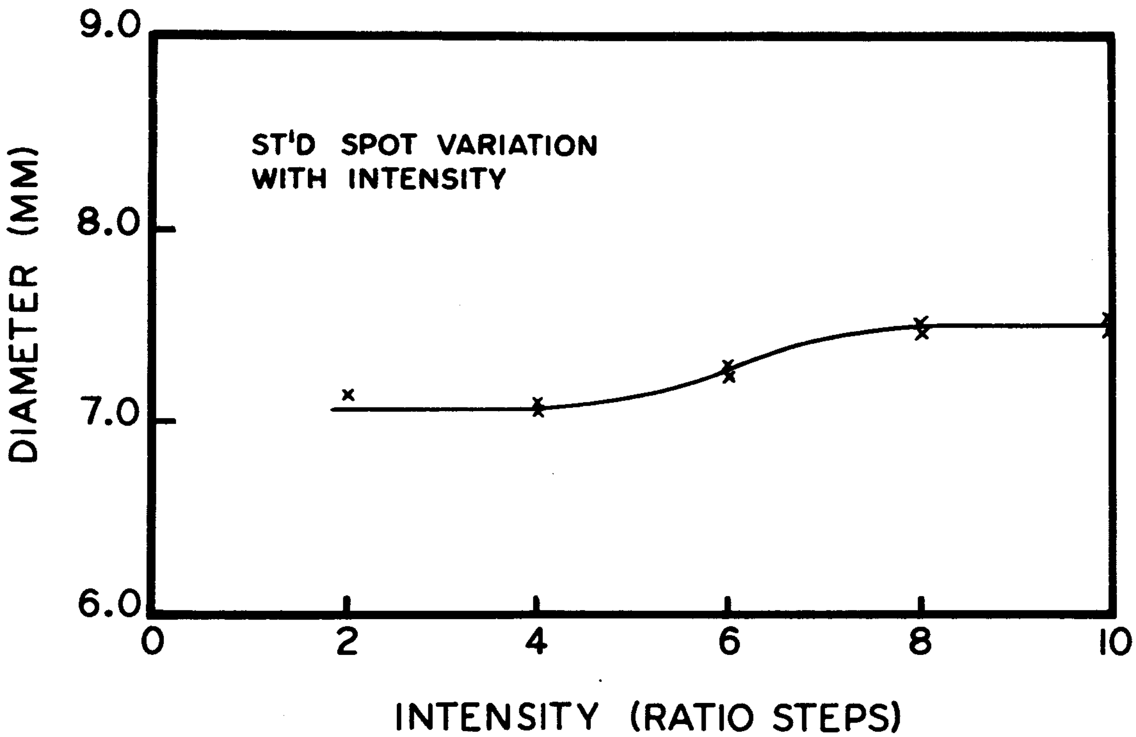

9.0
8.0
7.0
6.0
DIAMETER (MM)
ST'D SPOT VARIATION
WITH INTENSITY
0
2
4
6
8
10
INTENSITY (RATIO STEPS)

FIGURE 6

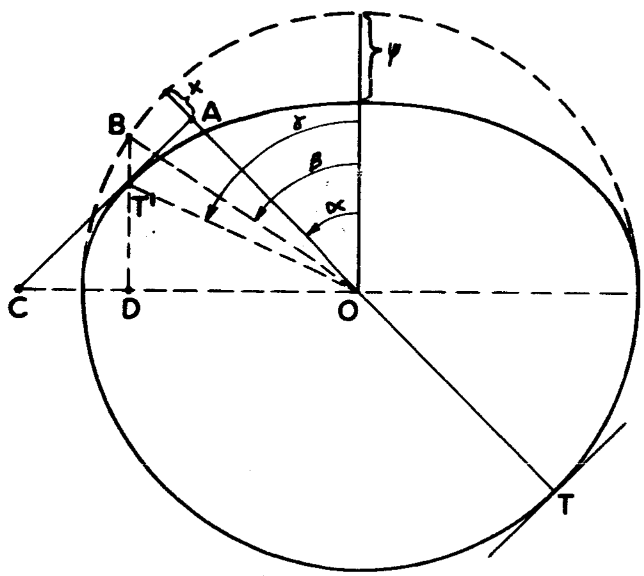


FIGURE 7

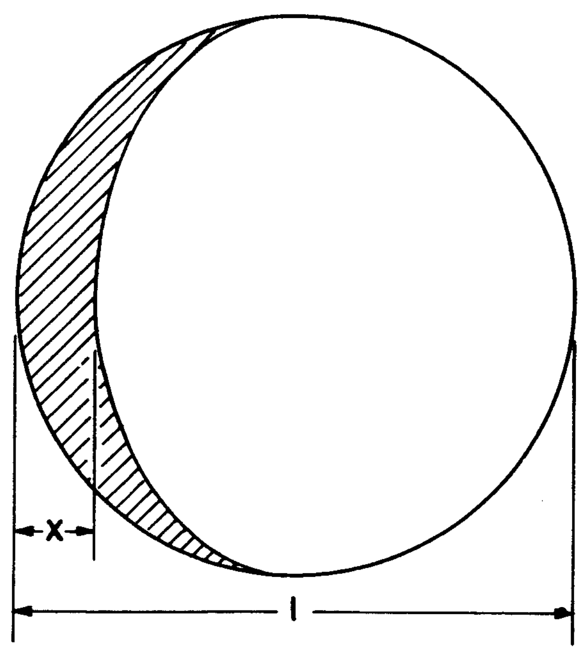


FIGURE 8

TABLE I

DIAMETER OF MARS

(Micrometer)

Date: 1924	Wavelength	Diameter (1 A. U.)
Aug - Sept	7600A	9.25'' ± 0.03''‡

TABLE II

DIAMETER OF MARS

(Micrometer)

Date: 1924	Wavelength	Diameter (1 A. U.)
Aug - Sept	4400A	9.53'' ± 0.04''*

---

‡ Mean of 39 values.

* Mean of 32 values.

TABLE III

DIAMETER OF MARS

(Micrometer)

Date: 1926	Wavelength	Diameter (1 A.U.)
Oct - Nov	7600A	9.25" ± 0.04" (1)
	6500	9.30 ± 0.04 (2)
	5700	9.56 ± 0.05 (3)
	4300	9.61 ± 0.04 (4)
	4400	9.68 ± 0.05 (5)
	3700	9.72 ± 0.07 (6)

(1) Mean of 15 values.
(2) " " 13 "
(3) " " 16 "
(4) " " 16 "
(5) " " 16 "
(6) " " 14 "

TABLE IV

DIAMETER OF MARS

(Microphotometer)

Date: 1924	Wavelength	Diameter (1 A. U.)
Aug - Oct	7600A	10.07" ± 0.07 (1)
	4400A	10.74" ± 0.08 (2)

TABLE V

DIAMETER OF MARS

(Microphotometer)

Date: 1926	Wavelength	Diameter (1 A. U.)
Oct - Nov	7600A	9.96" ± 0.13 (3)
	3700A	10.94" ± 0.26 (4)

---

(1) Mean of 10 values.
(2) " " 8 "
(3) " " 4 "
(4) " " 4 "